Gulf Sturgeon (*Acipenser oxyrinchus desotoi*) 5 -Year Review: Summary and Evaluation.
http://ecos.fws.gov/docs/five_year_review/doc2620.pdf

Notes: Searched document for "oxygen".

P. 17: Sulak et al. (2004) suggest that successful egg fertilization for Gulf sturgeon may require a relatively narrow range of pH and calcium ion concentration. These parameters vary substantially along the length of the Suwannee River. Egg and larval development are also vulnerable to various forms of pollution and other water quality parameters (e.g., temperature, dissolved oxygen (DO)).

P. 19: While laboratory results are not available for Gulf sturgeon, signs of stress observed in shortnose sturgeon exposed to low DO included reduced swimming and feeding activity coupled with increased ventilation frequency (Campbell and Goodman 2004). Niklitschek (2001) observed that egestion levels for Atlantic and shortnose sturgeon juveniles increased significantly under hypoxia, indicating that consumed food was incompletely digested. Behavioral studies indicate that Atlantic and shortnose sturgeon are quite sensitive to ambient conditions of oxygen and temperature: in choice experiments juvenile sturgeons consistently selected nomoxic over hypoxic conditions (Niklitschek 2001). Beyond escape or avoidance, sturgeons respond to hypoxia through increased ventilation, increased surfacing (to ventilate relatively oxygen-rich surficial water), and decreased swimming and routine metabolism (Nonnette et al. 1993, Crocker and Cech 1997, Secor and Gunderson 1998, Niklitschek 2001).

Appendix E, Biological Opinion and Conference Report on the U.S. Army Corps of Engineers, Mobile District, Interim Operating Plan for Jim Woodruff Dam and the Associated Releases to the Apalachicola River, 5 Sept 2006, USFWS.
http://www.sam.usace.army.mil/Portals/46/docs/planning_environmental/acf/acf_info/docs/IOPFinalEA_APPENDIX_E.pdf

P. 21: Gulf sturgeon require large areas of diverse habitat that have natural variations in water flow, velocity, temperature, and turbidity (USFWS and GSMFC 1995; Wakeford 2001). Laboratory experiments indicate that Gulf sturgeon eggs, embryos, and larvae have the highest survival rates when temperatures are between 15 and 20oC (59 and 68oF). Mortality rates of Gulf sturgeon gametes and embryos are highest when temperatures are 25oC (77oF) and above (Chapman and Carr 1995) (see section 2.1.3.2 for more details). Researchers have documented temperature ranges at Gulf sturgeon resting areas between 15.3 and 33.7oC (59.5 and 92.7oF) with dissolved oxygen levels between 5.6 and 9.1 milligrams per liter (mg/l) (Morrow *et al.* 1998; Hightower *et al.* 2002). Compared to other fish species, sturgeon have a limited behavioral and physiological capacity to respond to hypoxia (insufficient oxygen levels) (Secor and Niklitschek 2001). Basal metabolism, growth, consumption, and survival are sensitive to changes in oxygen levels (Secor and Niklitschek 2001). In laboratory experiments, young shortnose sturgeon (*A. brevirostrum*) (less than 77 days old) died at oxygen levels of 3.0 mg/l and all sturgeon died at oxygen levels of 2.0 mg/l (Jenkins *et al.* 1993). Data concerning the temperature, oxygen, and current velocity requirements of cultured sturgeon are being collected. Researchers plan to use information gained from these laboratory experiments on hatchery-reared sturgeon to develop detailed information on water flow requirements of wild sturgeon throughout different phases of their freshwater residence (Wakeford 2001).

P. 25: Currently, seven rivers are known to support reproducing subpopulations of Gulf sturgeon. Table 2.1.4.A lists these rivers and most-recent estimates of subpopulation size. At this time, the Service characterizes the status of the species as stable. Identifying specific limiting factors to the species' recovery is difficult due to its long life span, large range, and utilization of diverse riverine, estuarine, and marine habitats.

P. 41:

Table 2.1.4.A. Estimated size of known reproducing subpopulations of Gulf sturgeon.

River	States	Estimated Gulf Sturgeon Subpopulation Size[1]	Source
Pearl	LA, MS	300	Rogillio *et al.* 2002
Pascagoula	MS	162-216	Heise *et al.* 1999a; Ross *et al.* 2001b
Escambia	AL, FL	506-687	F. Parauka, USFWS, pers. comm. 2005
Yellow	AL, FL	500-911	Berg *et al.* 2004
Choctawhatchee	AL, FL	2000-3000	F. Parauka, USFWS, pers. comm. 2005
Apalachicola	FL	270-321	USFWS 1998; USFWS 1999
Suwannee	FL	5500-7650	Sulak and Clugston 1999; Pine and Allen 2001

[1] All estimates listed apply to the portion of the subpopulation exceeding a minimum size, which varies between researchers according to the sampling methods used.

P.79: **3.6.2.4 Water quality**
Water quality (including temperature, turbidity, dissolved oxygen, and chemical constituents) that meets or exceed the current aquatic life criteria established under the Clean Water Act (33 U.S.C. 1251-1387). A wealth of evidence that supports the dependency of the mussels on good water quality. As animals with limited mobility, mussels must tolerate the full range of water quality parameters to persist in that stream. Most mussels are considered sensitive to low dissolved oxygen (DO) levels, high temperatures, and unionized ammmonia (Fuller 1974; Johnson 2001; Sparks and Strayer 1998; Augspurger *et al.* 2003).

Biological Opinion, April 8, 2015. SR30/US 98 Pensacola Bay Bridge Federal Highway Administration Florida Department of Transportation Escambia and Santa Rosa Counties, Florida; FWS No. 04EF3000-2013-F-0264.
http://pde.pensacolabaybridge.com/documents/2015-05/us-fish-and-wildlife-service-biological-opinion/us-98-pensacola-bay-bridge-final-bo-2015-04-08.pdf

P. 18. Pensacola Bay is vulnerable to periods of hypoxia, or low dissolved oxygen, during the summer months (UWF 2009; USEPA 2005). Extreme weather events, such as hurricanes, may result in periods of degraded water quality and hypoxic conditions. The extent of low oxygen conditions (defined here as < 2 mg/l) in Pensacola Bay increases as temperature and stratification increase (USEPA 2005). Sturgeons are more sensitive to hypoxia than other well known, oxyphillic species, such as rainbow trout (Secor and Niklitschek 2001). Sturgeons have a limited behavioral and physiological capacity to respond to hypoxia, and basal metabolism, growth, consumption, and survival are sensitive to changes in oxygen levels (Secor and Niklitschek 19, 2001). The sensitivity of sturgeons to low dissolved oxygen (DO) conditions appears to decrease as the fish matures, with YOY fish being the most sensitive. In laboratory experiments, young (< 77 days old) shortnose sturgeon (*A. brevirostrum*) died at oxygen levels of 3.0 mg/l and all sturgeon died at oxygen levels of 2.0 mg/l (Jenkins et al. 1993). Niklitschek and Secor (2009) tested YOY Atlantic sturgeon at 20°C and found a no effect at 6.70 mg/L, high mortality at 3.47 mg/L, and chronic deleterious effects of 4.82 mg/L. Lewis (2010) summarized DO collection data from 22 sites in the Yellow River from the 2009 Florida STORET database. Dissolved oxygen throughout the river was fairly high (> 6 mg/L). Several sites had values between 4-5 mg/L; however, the low values usually occurred during single sampling events, and observed concentrations were only below 4 mg/L on one occasion.

Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: I. Laboratory results. Edwin J. Niklitschek a,⁎, David H. Secor b. Journal of Experimental Marine Biology and Ecology. 2009. http://secor.cbl.umces.edu/sturgeon/Niklitschek&Secor_JEMBE_2009%20Part%201.pdf

Intro, p. 1: Sturgeons have been considered as indicator species due to their particularly low tolerance to hypoxia, which can exceed well known oxyphilic species such asOncorhynchusmykiss (Klyashtorin,1982). This tolerance has been shown to be reduced at high temperature (Secor and Gunderson,1998) and salinity levels (Niklitschek, 2001), suggesting that the areas of suitable nursery habitats could be largely reduced in summer months (Collins et al., 2000; Niklitschek and Secor, 2005).

P. S157: 4.1. Sensitivity of sturgeons to hypoxia Our results support the idea that average sensitivity of sturgeons to hypoxia is higher than in other fishes, exceeding well known oxyphyllic species, such as rainbow trout Oncorynchus mykiss (Klyashtorin, 1976; Secor and Niklitschek, 2002). A heightened sensitivity of sturgeons to hypoxia has been ascribed to an inefficient oxyregulatory system associated with ancestral morphological and physiological traits (Klyashtorin, 1976, 1982). These traits include less efficient gill ventilation, low cardiac performance (Agnisola et al., 1999), and lower affinity of hemoglobin to oxygen (Baker et al., 2005). This overall pattern of especially high sensitivity of sturgeons to hypoxia seems counterintuitive. Many sturgeon populations may have historically used shallow warm estuaries, where hypoxia occurred naturally in the deepest waters before recent anthropogenic effects (Burggren and Randall, 1978; Crocker and Cech, 1997). At the same time, this limited ability to adapt to hypoxia could explain the lack of recovery observed for sturgeon populations inhabiting heavily eutrophied estuaries along the East Coast of the United States (Collins et al., 2000). Scarce literature has focused on estimating lethal hypoxia effects on sturgeon species. Here, we provided new information on sub-acute lethal DO levels, although we avoided short-term lethal treatments to conserve a limited supply of experimental animals and to prevent undue animal suffering. Accumulated mortality (21 d) in our experiments reached 30% under hypoxia (40% DOSAT) at 20 °C (salinity=8), increasing to nearly 50% at 28 °C. Secor and Gunderson (1998) found much higher mortality rates (N85%) under similar hypoxia levels (37%–44% DO saturation) after 10-d exposure experiments conducted at 26 °C. Different laboratory settings or source of juveniles (different Hudson River parentage) may have contributed to these differences, but they suggest that survival responses reported here may be conservative. Jenkins et al. (1993) conducted acute mortality (6 h) experiments on YOY Atlantic sturgeon and observed 86–100% mortality for 25–64 d old fish at 30% DO saturation and 22.5 °C, while older juveniles (100–310 d old) experienced only 12–20% mortality under the same conditions. The latter mortality rates are consistent with results reported here for older YOY.

P. S158: The effects of DOSAT on Atlantic sturgeon that we observed were intermediate to these previous studies, and highly temperature dependent. We observed similar metabolic rates at 70 and 100% DOSAT, followed by a strong reduction in routine metabolism when dissolved oxygen saturation was lowered from 70% to 40%. Such saturation values are equivalent to DO concentrations of 5.24 and 2.99 mg l−1, respectively, at 28 °C and salinity 8.

P. S158-159: 4.4. Defining hypoxia thresholds for juvenile Atlantic sturgeon and other estuarine fishes The additive and interactive effects we found for DO, temperature and salinity should have major consequences for juvenile Atlantic Our results show the importance of considering temperature and salinity as relevant covariates for hypoxia criteria definitions: considering both their effects upon physiological rates and upon oxygen solubility in water and blood (Holeton and Randall, 1967). For illustration purposes, if optimal growth or survival rates were used as criteria to set a hypoxia threshold for juvenile Atlantic sturgeon, that value would rise from 40 to 70% DOSAT if temperature increased from 12 to 20 °C. At salinity 1 these values would correspond to concentrations of 4.3 and 6.3 mg l−1, respectively. At salinity 29, on the other hand, the same thresholds would correspond to concentrations of 3.6 and 5.4 mg l−1, respectively. At this point, it must be emphasized that "percent DO saturation" or "partial pressure of DO" are the biologically relevant factors for hypoxia, since these, rather than oxygen concentration, represent what physically determines fish oxygen uptake from the surrounding water (Cech, 1990; Kiceniuk and Colbourne, 1997). Hypoxia has been frequently defined by fixed oxygen criteria, commonly at either 2 ml l−1 or 2 mg l−1 (Diaz and Rosenberg, 1995; Diaz, 2001; Wu, 2002; US-EPA, 2003). A broader operational definition considers hypoxia as any oxygen concentration reduced from full saturation that impairs living (US-EPA, 2003). To expand this definition further, we propose to define hypoxia as any oxygen concentration reduced from full saturation that produces measurable negative effects upon physiological and survival rates of a given species.

Early Life History Stages of Gulf Sturgeon in the Suwannee River, Florida. Transactions of the American Fisheries Society 127(5):758-771 · September 1998. http://www.tandfonline.com/doi/full/10.1577/1548-8659(1998)127%3C0758%3AELHSOG%3E2.0.CO%3B2?src=recsys&

Florida spring water, typically very low in oxygen tensions (0–4 mg/L; Rosenau et al. 1978Rosenau, J. C., Faulkner, G. L., Hendry, C. W. Jr. and Hull, R. W.1978. *Springs of Florida*, Bureau of Geology, Bulletin 31 (revised 1977) Tallahassee, Florida: State of Florida.), is probably inhospitable to early juveniles. Jenkins et al. (1995)Jenkins, W. E., Smith, T. I. J., Heyward, L. D. and Knott, D. M.1995. Tolerance of shortnose sturgeon, *Acipenser brevirostrum*juveniles to different salinity and dissolved oxygen concentrations. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies*, 47(1993): 476–484. demonstrated that juvenile shortnose sturgeon (age 11–330 d) begin to encounter mortality when held at DO concentrations below 3.5 mg/L in the laboratory. Young fish (age 64 d) were particularly susceptible, exhibiting 86% mortality when held for 6 h at 2.5 mg DO/L.

Science Information to Support Missouri River Scaphirhynchus albus (Pallid Sturgeon) Effects Analysis
https://pubs.usgs.gov/of/2015/1226/ofr20151226.pdf

Aquaculture Few published studies were found that addressed artificial propagation or culture of pallid sturgeon. Much of the information learned through the culture of pallid sturgeon that may be of value for informing EA models may exist as records housed at the hatcheries and research facilities involved with propagation. These facilities may possess data regarding egg fertilization or hatch rates, survival from egg to free embryo, or the influence of water quality on developing eggs or young sturgeon. Original research that may provide useful insight on the importance of culture-related stressors (that is, acute ammonia exposure, low dissolved oxygen, and crowding) on juvenile pallid sturgeon was conducted by Nelson and Small (2014); their results indicate a low stress response to ammonia, a substantial response to low dissolved oxygen, and persistent response to crowding. These results are broadly similar to an earlier study (Barton and others, 2000) that concluded that pallid sturgeon juveniles do not respond strongly to handling stress during aquaculture operations.

Ambient water-quality monitoring on the Lower Missouri River has demonstrated summer episodes when dissolved oxygen concentrations are below 5 milligrams per liter, which is a threshold that may be stressful especially to 14 age-0 and juvenile sturgeon (Blevins, 2011).

Acute Sensitivity of Juvenile Shortnose Sturgeon to Low Dissolved Oxygen Concentrations
Jed G. Campbell & Larry R. Goodman
Pages 772-776 | Received 19 Apr 2002, Accepted 01 Oct 2003, Published online: 09 Jan 2011
http://afs.tandfonline.com/doi/full/10.1577/T02-070.1?src=recsys

We conducted experiments to obtain information on the acute sensitivity of young-of-year shortnose sturgeon to a low dissolved oxygen (DO) concentration. Flow-through tests were conducted with hatchery-produced fish exposed to the ranges of DO, salinity, and temperature expected in the southeastern United States coastal river–estuary interfaces during spring and summer. The estimated concentration lethal to 50% of the test organisms (the LC50 value) after 24 h that we derived for approximately 77-d-old fish tested at 2‰ salinity and a nominal temperature of 25°C was 2.7 mg/L (32% saturation). An estimated LC50 of 2.2 mg/L (26% saturation) was obtained for approximately 104-d-old fish tested at 4‰ and 22°C. The 24-h, 48-h, and 72-h LC50 values for approximately 134-d-old fish tested at 4.5‰ and 26°C were also 2.2 mg/L (28% saturation). However, the test with approximately 100-d-old fish at 2‰ and a nominal temperature of 30°C yielded a 24-h LC50 of 3.1 mg/L (42% saturation). These data should be of value in derivating DO-protective values for shortnose sturgeon inhabiting estuaries along the Atlantic coast.

Bambarger, R. 2006. FRESHWATER MUSSEL COMMUNITIES OF THE FLORIDA PARISHES, LOUISIANA: THE IMPORTANCE OF SPATIAL SCALE. MS Thesis. Louisiana State University.
http://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=5035&context=gradschool_theses

Studies conducted at the microhabitat spatial scale are most common in the literature. Many scientists have argued that sediment composition is a powerful determinant of mussel abundance and diversity (Harman 1972, Green 1971, Strayer 1981, Brown and Johnson 2000, Brown and Banks 2001), while others concluded that it poorly predicts these same responses (Downing et al 2000, Vaughn 1997, Michaelson and Neves 1995, Huehner 1987). Strayer and Ralley (1993) examined the distribution of six species of unionids in New York and found that sediment type did not predict mussel abundance. Strayer et al. (1994) also concluded that sediment type alone had no demonstrable impact on mussel assemblage structure. Other microhabitat descriptors such as dissolved oxygen, specific conductance, temperature and depth have also been used extensively in attempts to predict community structure. While intuitively appealing, quantitative studies indicate weak relationships between mussel distribution and most microhabitat scale descriptors (Arbuckle and Downing 2002, Poole and Downing 2004, McRae and Burch 2000, Layzer and Madison 1995, Salmon and Green 1985, Brim-Box et al 2002).

Alexander, J.S., Wilson, R.C., and Green, W.R., 2012, A brief history and summary of the effects of river engineering and dams on the Mississippi River system and delta: U.S. Geological Survey Circular 1375, 43 p.
https://pubs.usgs.gov/circ/1375/C1375.pdf

P. 1: The decline of the pallid sturgeon may be attributable to channelization of the Missouri River above St. Louis, Missouri. The Missouri River supports a rich fish community and remains relatively intact. Nevertheless, the widespread and long history of human intervention in river discharge has contributed to the declines of about 25 percent of the species.

P. 31: Fish that inhabit swift-current habitats in the unimpounded lower Mississippi River have not declined as much as in the upper Mississippi River (Pflieger, 1975; Baker and others, 1991) with the exception of the pallid sturgeon. The decline of the pallid sturgeon, a native species which is listed as endangered by the U.S. Fish and Wildlife Service, may be attributable to channelization of the open river below St. Louis, Mo. (Wiener and others, 1998).

Altenritter, M.E.L., Wieten, A.C., Ruetz III, C.R., Smith, K.M., 2013. Seasonal Spatial Distribution of Juvenile Lake Sturgeon in Muskegon Lake, Michigan, USA. Ecology of Freshwater Fish 22, 467-478.

From Abstract: Canonical correspondence analysis showed that fish species composition was associated with specific conductivity, vegetation cover, turbidity and pH, suggesting species–environment relationships are similar to those shown for Great Lakes coastal wetlands.

Brown, K. M. and P. D. Banks (2001). "The conservation of unionid mussels in Louisiana rivers: diversity, assemblage composition and substrate use." Aquatic Conservation: Marine and Freshwater Ecosystems 11(3): 189-198. http://www.bioone.org/doi/abs/10.1899/12-137.1

Abstract Unionoids are important in aquatic ecosystems, but despite their continued decline in diversity, few multifactorial studies have been done to identify determinants of their distribution and diversity. We studied the effects of multiple environmental factors on species richness and abundance at 65 sites in 6 major watersheds in the Pine Hills region, Louisiana. We surveyed in-stream habitat variables, land use/cover, and the co-occurring fish assemblages in 2nd- through 6th-order streams. A structural equation model suggested that 2 major latent variables were important: 1) reduced habitat disturbance, influenced by lower current velocity, substratum composed mostly of fine sediments, and increasing stream order, and 2) agricultural land use in riparian corridors and associated reduced water quality. These 2 latent variables explained 84% of mussel species richness and 48% of total mussel abundance. Mussel, but not host-fish species richness and abundance increased with stream order. Sites in the lower river basins had increased amounts of fine sediments and lower current velocities. We suggest that the lower river basins have extensive riparian wetlands that ameliorate the effects of frequent floods, thus mediating hydrologic disturbance and increasing mussel diversity.

Kynard, B., Breece, M., Atcheson, M., Kieffer, M., Mangold, M., 2009. Life History and Status of Shortnose Sturgeon (*Acipenser brevirostrum*) in the Potomac River. Journal of Applied Ichthyology 25, 34-38. http://web.ornl.gov/~zij/mypubs/sturgeon/JagerShortnosePVA-SERDP-2013.pdf

Abstract Southern populations of the federally endangered Shortnose Sturgeon Acipenser brevirostrum are considered to be at greater risk of extirpation than northern populations. Our study focused on the Ogeechee River, Georgia, a small, undeveloped, coastal river that supports a population with fewer than 300 Shortnose Sturgeon. We designed a population viability analysis (PVA) model to represent and quantify the demographic influences of three factors (poor water quality, intrusion of saline water via rice canals, and incidental harvest) on the viability of this population. As an isolated population, only 75% of simulated populations persisted beyond a 20-year time horizon with all factors simulated. However, immigration from the Altamaha River may help to support the population. We quantified population persistence with and without simulating each factor and found that (1) incidental harvest had no effect on simulated persistence, (2) poor water quality decreased simulated persistence by 29%, primarily due to low oxygen conditions in summer, and (3) roughly one-third of this effect was attributed to rice canals (premature exposure of juveniles to high salinities). Simulated recruitment to age 1 was limited by a habitat squeeze between densitydependent starvation upstream near the spawning grounds and premature exposure to salinity downstream. These results highlight a need for research on availability of summer refuge and freshwater rearing habitat. As these results derived from a PVA model, which required many assumptions, they should be considered preliminary. Further field research is needed to confirm those results where it is possible to test intermediate predictions. We conclude by suggesting that efforts to maintain or increase the number of viable populations of Shortnose Sturgeon in southern U.S. rivers will probably require an understanding of (1) source-sink dynamics between populations in rivers with access to adequate freshwater rearing habitat and those without, and (2) the effects of climate change.

P. 736: ***Dissolved oxygen*—**Tolerances to low DO have been studied for early life stages of Shortnose Sturgeon (Niklitschek 2001; Secor and Niklitschek 2001), but not for adults. According to Secor and Niklitschek (2001), age-0 Shortnose Sturgeon began to exhibit physiological and behavioral changes to DO levels below 4.5 mg/L when temperatures are in the range of 22–27◦C (Niklitschek and Secor 2005). This was caused by increased respiration. Campbell and Goodman (2004) found LC50 values (i.e., concentrations lethal to 50% of test fish) varied from 2.2 to 3.1 mg/L depending on the age of age-0 sturgeon and the temperature.

Morrow, J. V. J., J. P. Kirk, K. J. Killgore, H. Rogillio and C. Knight (1998). "Status and recovery potential of gulf sturgeon in the Pearl River system, Louisiana–Mississippi." North American Journal of Fisheries Management 18(4): 798-808. http://www.tandfonline.com/doi/pdf/10.1577/1548-8675%281998%29018%3C0798%3ASARPOG%3E2.0.CO%3B2?needAccess=true

Abstract From 1992 through 1996, 257 Gulf sturgeon *Acipenser oxyrinchus desotoi* were captured in the Pearl River system of Louisiana and Mississippi, but adults (>130 cm fork length) constituted less than 2% of the catch. The summer population size in 1996, estimated by mark–recapture methods, was 292 individuals that were age 2 or older. Instantaneous total mortality rate (Z), estimated with a catch curve, was 0.41, for an annual mortality rate of 34%. Modeling the population with $Z = 0.41$ resulted in declining populations under two different recruitment scenarios. Mortality rates will have to be reduced to $Z = 0.16–0.24$ for the population to be self-sustaining by 2023, the target year in the Gulf Sturgeon Recovery Plan. Mean fork length of Gulf sturgeon in the Pearl River system was significantly larger in 1970 than in 1985 and 1992–1996, indicating that the population may not have improved since 1985. An increase in population size should be detectable within 6 years of achieving acceptable levels of mortality. Efforts to reduce mortality should focus on commercial bycatch and improving winter habitat in the Lake Pontchartrain estuary and summer habitat in the Pearl River system. Weirs in the Pearl and Bogue Chitto rivers need further study to determine if improved fish passage would improve recruitment and survival of Gulf sturgeon.

- causes of mortality have not been identified
- Environmental changes in the Pearl River–Lake Pontchartrain system may also affect mortality, including the construction of one main-stem dam and two low-head weirs, dredging in the Pear River and tributaries of Lake Pontchartrain, and eutrophication of Lake Pontchartrain and its tributaries
- however, since 1970, increased nutrient levels in Lake Pontchartrain have caused increased turbidity, reduction in grass beds, and changes in benthic communities (Stone et al. 1980) and may have affected Gulf sturgeon mortality rates. Until the biology and migration patterns of Gulf sturgeon in this system are better known, we can only speculate about effects of environmental changes on mortality.

Niklitschek, E.J., Secor, D.H., 2005. Modeling Spatial and Temporal Variation of Suitable Nursery Habitats for Atlantic Sturgeon in the Chesapeake Bay. Estuarine, Coastal and Shelf Science 64, 135-148. https://www.researchgate.net/publication/248575859_Modeling_Spatial_and_Temporal_Variability_of_Suitable_Nursery_Habitats_for_Atlantic_Sturgeon_in_Chesapeake_Bay

For the period 1993–2002, spatial and temporal patterns in water quality effects (temperature, dissolved oxygen [DO] and salinity) on potential production were evaluated. In addition, two forecasted scenarios were modeled: one implementing newly revised U.S. Environmental Protection Agency (EPA) DO-criteria for the Chesapeake Bay, and the other assuming a bay-wide increase of 1°C due to an underlying trend in regional climate. Atlantic sturgeon's low (survival/growth) tolerance to temperatures >28°C was a critical constraint during their first 1–2 summers of life. Hatched in freshwater (spring to mid-summer), young-of-the-year were predicted to occupy cooler (deeper) areas as temperature approached sub-lethal levels. While most thermal refuges were located down-estuary, a large fraction of potential refuges were unsuitable due to persistent hypoxia and/or salinity levels beyond the limited osmoregulatory capabilities of early juvenile Atlantic sturgeon.

Biological Opinion: Endangered Species Act Section 7 Consultation on the **U.S. Army Corps of Engineers Mobile District Update of the Water Control Manual for the Apalachicola-Chattahoochee-Flint River Basin in Alabama, Florida, and Georgia and a Water Supply Storage Assessment**
Prepared by: U.S. Fish and Wildlife Service Panama City Field Office, Florida September 14, 016
USFWS Log No: 04EF3000-2016-F-0181.
https://www.fws.gov/panamacity/resources/USFWSBiologicalOpinionforACFWaterControlManual2016.pdf

- *Nothing new from this BO*

Cech, J. J., Jr., and C. E. Crocker. 2002. Physiology of sturgeon: effects of hypoxia and hypercapnia. *J. Appl. Ichthyology* 18:320–324. http://dx.doi.org/10.1046/j.1439-0426.2002.00362.x

- *Examined – White Sturgeon from Pacific NW. Not informative.*

Cech, J. J., Jr., S. J. Mitchell, and T. E. Wragg. 1984. Comparative growth of juvenile white sturgeon and striped bass: effects of temperature and hypoxia. *Estuaries7:12-18.* *http://www.worldcatlibraries.org/wcpa/top3mset/b5321b41146335c4.html*

- *Examined. Not related.*

Bowen, B.W., Avise, J.C., 1990. Genetic Structure of Atlantic and Gulf of Mexico Populatioins of Sea Bass, Menhaden and Sturgeon: Influence of Zoogeographic Factors and Life-History Patterns. Marine Biology 107, 371-381.

- *Genetic Discussion. Nothing to add.*

Mussel Survey, December 1992, "Red River Waterway Shreveport, LA, to Daingerfield, TX, Reach Reevaluation Study In-Progress Review." Technical Report of the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

- *All references are to the Texas Heelsplitter. No oxygen-related info other than they stated that readings were collected.*

Nelson, L.R., Small, B.C., 2014. Stress Responses in Pallid Sturgeon Following Three Simulated Hatchery Stressors. North American Journal of Aquaculture 76, 170-177. http://www.tandfonline.com/doi/full/10.1080/15222055.2014.886651?scroll=top&needAccess=true

- *Studied effects of hatchery conditions on pallid sturgeon. Propagation/fish culture-related.*

Cope, W.G., Holliman, F.M., Kwak, T.J., Oakley, N.C., Lazaro, P.R., Shea, D., Augspurger, T., Law, J.M., Henne, J.P., Ware, K.M., 2011. Assessing Water Quality Suitability for Shortnose Sturgeon in the Roanoke River, North Carolina, USA with an *In Situ* Bioassay Approach. Journal of Applied Ichthyology 27, 1-12. http://onlinelibrary.wiley.com/doi/10.1111/j.1439-0426.2010.01570.x/abstract

- *Not DO-related.*

Helfrich, L.A., R.J. Neves, and H. Chapman. 2009. Sustaining America's Aquatic Biodiversity - Freshwater Mussel Biodiversity and Conservation. VACoop. 420-523 https://pubs.ext.vt.edu/420/420-523/420-523.html

- *General, not DO-related.*

Meadows, D., 2007. Gulf Sturgeon Critical Habitat. National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Office of Protected Resources. http://www.fisheries.noaa.gov/pr/species/fish/gulf-sturgeon.html

- *General info*

A bibliography of all known publications & reports on the Gulf sturgeon, *Acipenser oxyrinchus desotoi*
In cooperation with NOAA **By:** Melissa Price, Jennifer Adler, Chanda Littles, April Norem Randolph, Ursula A. Nash, Bethan Gillett, Michael Randall, Kenneth J. Sulak, Stephen J. Walsh, and Prescott Brownell
https://pubs.er.usgs.gov/publication/70048026

Not readily available but heavily cited:
Jenkins, W.E., T.I.J. Smith, L.D. Heyward, and D.M. Knott. 1993. Tolerance of shortnose sturgeon, *Acipenser brevirostrum*, juveniles to different salinity and dissolved oxygen concentrations. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:476-484.